Radiometric Cross-calibration of EO-1 ALI with L7 ETM+ and Terra MODIS Sensors

Gyanesh Chander
SGT, Inc., contractor to the U.S. Geological Survey (USGS) Earth Resources Observation and Science (EROS) Center, Sioux Falls, SD, 57198, USA.
Work performed under USGS contract G10PC00044. Telephone: 605-594-2554, Email: gchander@usgs.gov.

Introduction

- The Earth Observing-1 (EO-1) satellite was launched on November 21, 2000, as part of a one-year technology demonstration mission but was extended because of the scientific communities interest

- To evaluate the Advanced Land Imager (ALI) sensor capabilities as a precursor to Operational Land Imager (OLI) onboard Landsat Data Continuity Mission (LDCM, or Landsat 8), its measured top-of-atmosphere (TOA) reflectances were compared to the well-calibrated Landsat 7 (L7) Enhanced Thematic Mapper Plus (ETM+) and the Terra Moderate Resolution Imaging Spectroradiometer (MODIS) sensors in the reflective solar bands (RSB)

- The cross-calibration of ALI with ETM+ and MODIS was performed using near-simultaneous surface observations based on image statistics from areas observed by these sensors over four Desert sites (Libya 4, Mauritania 2, Arabia 1, and Sudan 1)

- The differences in the measured TOA reflectances due to Relative Spectral Response (RSR) mismatches were compensated by using a spectral band adjustment factor (SBAF), which takes into account the spectral profile of the target and the RSR of each sensor

Sensor Overview and Study Area

Table 1. ALI, ETM+, AND MODIS key specifications

Platform	EO-1	Landsat 7	Terra
Sensor	ALI	ETM+	MODIS
Launch date	November 21, 2000	April 15, 1999	December 18, 1999
Number of bands	10	8	36
Spatial resolution	10 m, 30 m	15 m, 30 m, 60 m	250 m, 500 m, 1 km
Swath	37 km	185 km	2330 km
Spectral coverage	0.4 – 2.5 μm	0.4 – 12.5 μm	0.4 – 14 μm
Pixel quantization	12 bit	8 bit	12 bit
Orbit type	Sun-synchronous	Sun-synchronous	Sun-synchronous
Equatorial Crossing Time	10:01 AM	10:00 AM	10:30 AM
Altitude	705 km	705 km	705 km
Repeat Cycle	16 days	16 days	1 – 2 days

- Recently, the Committee on Earth Observation Satellites (CEOS) Working Group on Calibration and Validation (WGCV) members of the Infrared Visible Optical Sensors (IVOS) sub-group has established a set of CEOS reference standard test sites for the post-launch calibration of space-based optical imaging sensors

- The six CEOS reference Pseudo Invariant Calibration Sites (PICS) are Libya 4, Mauritania 1, Mauritania 2, Algeria 3, Libya 1, and Algeria 5

- Due to the limited availability of ALI and Hyperion images over the CEOS PICS, only the following four sites were chosen in this study: Libya 4, Mauritania 2, Arabia 1, and Sudan 1

Table 2. ALI, ETM+, MODIS, AND HYPERION images used for the study

Site Name	WRS-2 Path/Row	ALI	ETM+	MODIS	Hyperion	ALI/ETM+/MODIS Same-Day Pairs
Libya 4	181 / 40	252	156	261	250	28
Mauritania 2	201 / 46	102	133	261	92	10
Arabia 1	165 / 47	157	161	220	155	22
Sudan 1	177 / 45	113	163	261	114	17

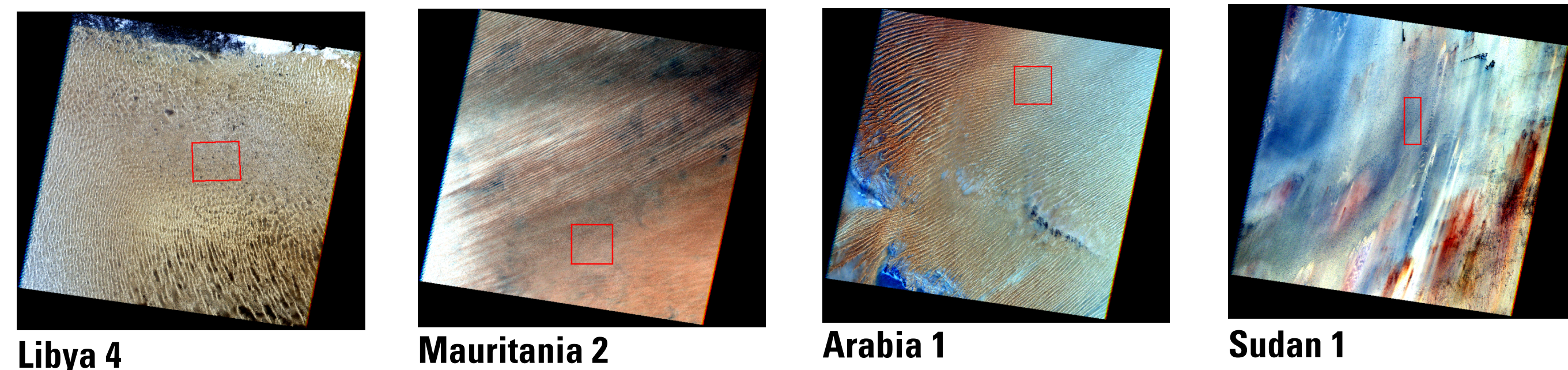**Libya 4**   **Mauritania 2**   **Arabia 1**   **Sudan 1**

Fig. 1. A sample image of the four PICS acquired using L7 ETM+ (note that the scales differ). It also illustrates the rectangular region of interest (ROI) that were used within the image-pairs.

Spectral Band Adjustment Factor (SBAF)

- The difference in the spectral bands between the two sensors introduces an intrinsic offset in the measured TOA reflectances

- A target ROI specific SBAF, which takes into account the spectral profile of the target and the RSR of the two sensors, can be used to compensate for this difference. The simulated reflectance for any sensor can be calculated by integrating the spectral response of the sensor with the hyperspectral TOA reflectance profile at each sampled wavelength, weighted by the respective RSR (equation 1)

- The integral in the numerator calculates the amount of in-band reflectance acquired in the respective RSR and is divided by the integral of the RSR of the sensor so there is no gain/loss due to the filter response function

- The SBAF is then calculated by integrating the spectral response of sensor A and B with the hyperspectral TOA reflectance profile at each sampled wavelength, weighted by the respective RSR as described above

- Therefore, the ratio of the two simulated reflectances gives a quantitative estimate of the difference between the observed reflectance of the two sensors arising from mismatching RSR for a given band and target

$$\overline{\rho}_{\lambda(A)} = \frac{\int \rho_\lambda\, RSR_\lambda\, d\lambda}{\int RSR_\lambda\, d\lambda}$$

$$SBAF = \frac{\overline{\rho}_{\lambda(A)}}{\overline{\rho}_{\lambda(B)}} = \frac{\left(\int \rho_\lambda\, RSR_{\lambda(A)}\, d\lambda\right) / \left(\int RSR_{\lambda(A)}\, d\lambda\right)}{\left(\int \rho_\lambda\, RSR_{\lambda(B)}\, d\lambda\right) / \left(\int RSR_{\lambda(B)}\, d\lambda\right)}$$

$$\overline{\rho}^{\,*}_{\lambda(A)} = \overline{\rho}_{\lambda(A)} / SBAF$$

where

- RSR_λ = Relative Spectral Response of the sensor [unitless]

- ρ_λ = Hyperspectral TOA reflectance profile [unitless]

- $\overline{\rho}_{\lambda(A)}$ = Simulated TOA reflectance for sensor A [unitless]

- $\overline{\rho}_{\lambda(B)}$ = Simulated TOA reflectance for sensor B [unitless]

- $\overline{\rho}^{\,*}_{\lambda(A)}$ = Compensated TOA reflectance for sensor A using the SBAF to match sensor B TOA reflectance [unitless]
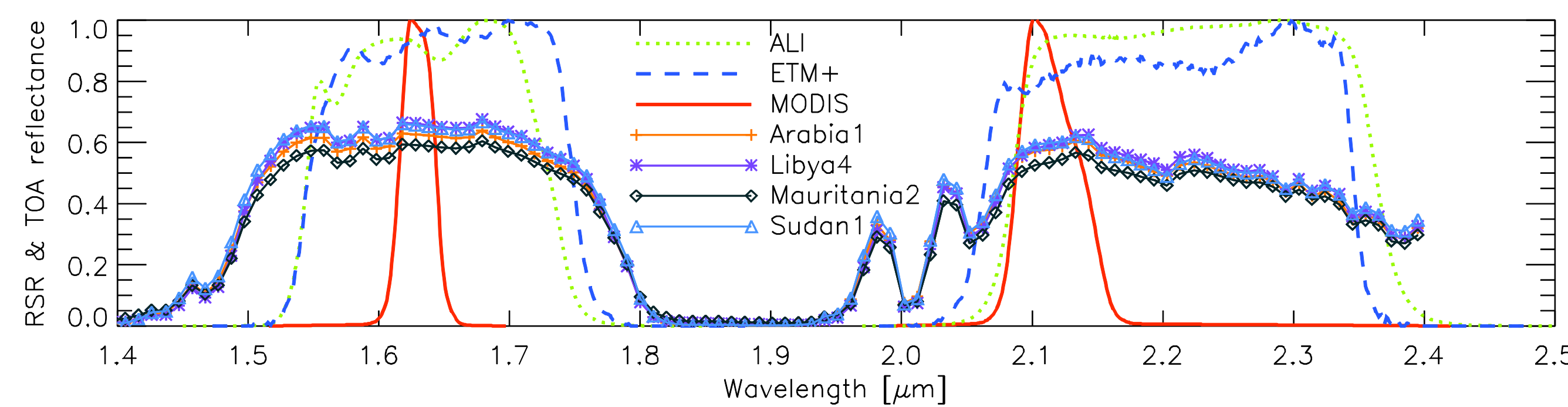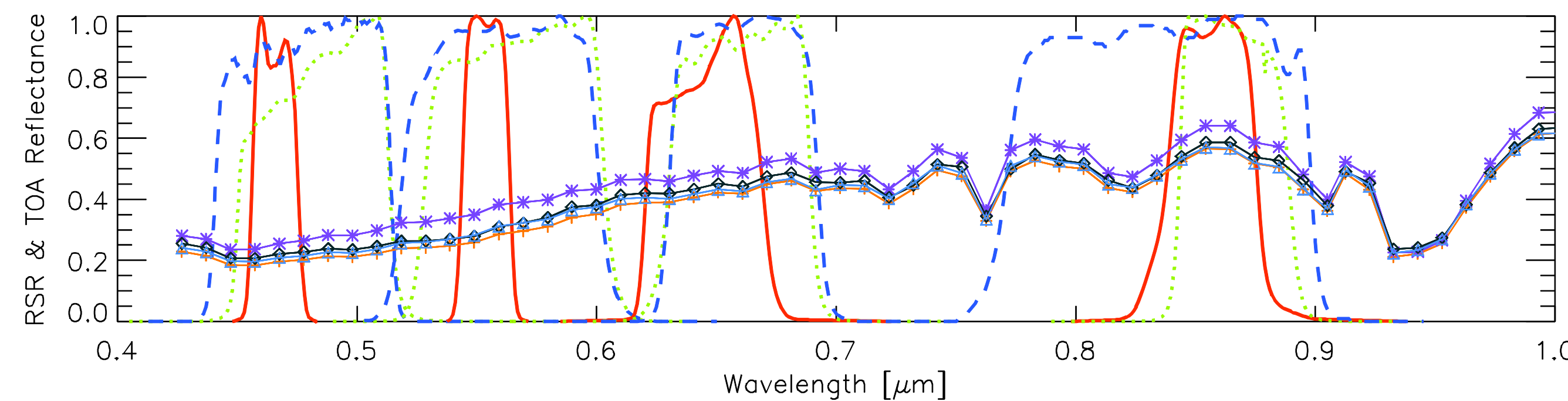

Fig. 2. Comparison of RSR profiles from the ALI, ETM+, and MODIS sensors along with the lifetime average EO-1 Hyperion TOA reflectance profile obtained for the four sites.
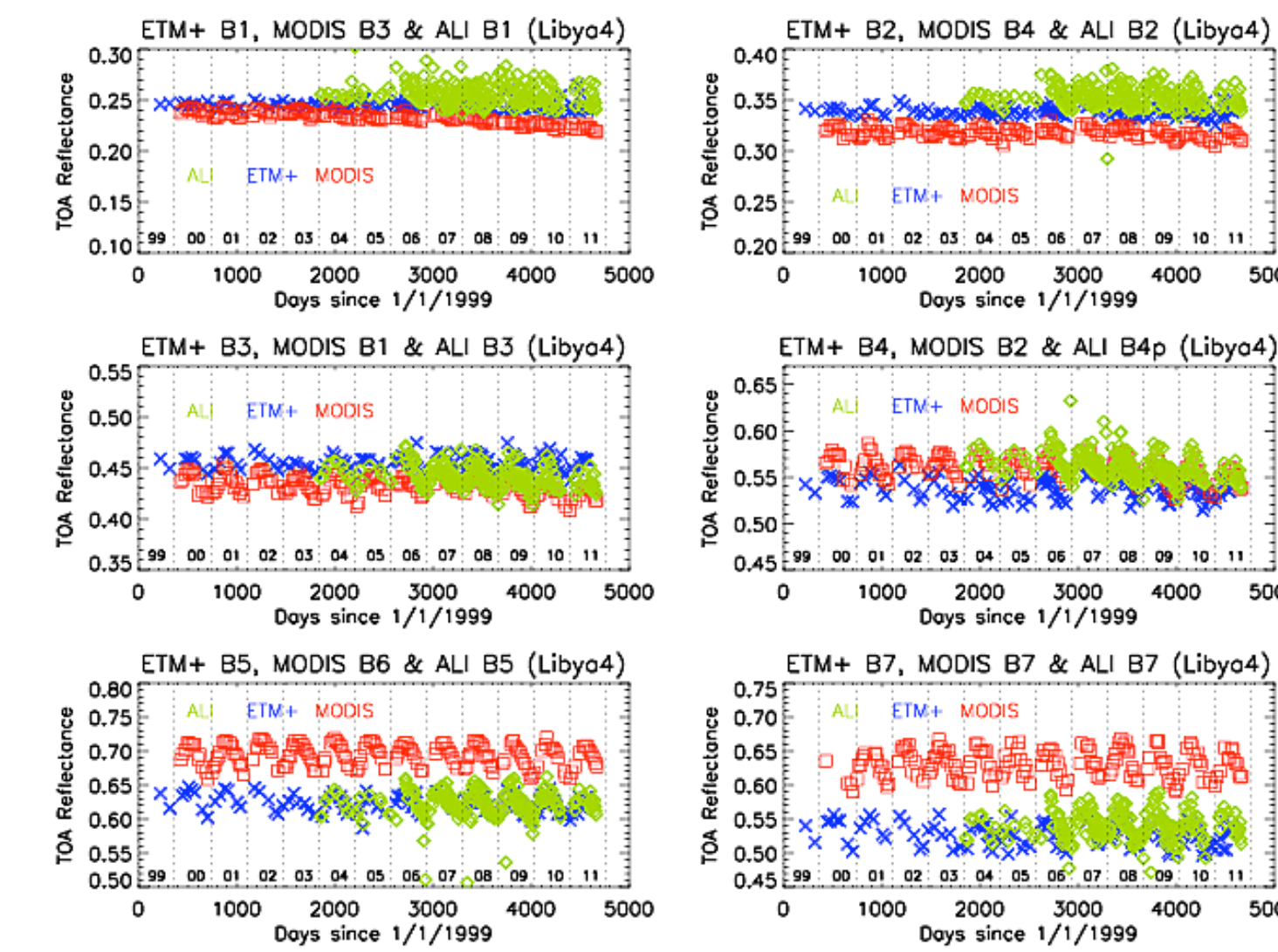
Results

Fig. 3. ALI, ETM+, and MODIS measured TOA reflectance trending over the Libya 4 site

- ALI TOA reflectance is denoted with green diamonds, ETM+ with blue crosses, and MODIS with red squares

- Overall, the long-term trends are extremely stable. In addition to the possible calibration bias between these sensors, the offset between the TOA reflectance trends of ALI, ETM+, and MODIS are likely caused by a combination of the RSR differences, spectral signature of the target, and the atmospheric composition during overpass

Fig. 4. Measured TOA reflectance ratio (ETM+/ALI) over the four PICS. The plot also shows a comparison of before and after SBAF compensation.

Table 3. Comparison of the ALI and ETM+ measured TOA reflectances before and after spectral compensation.

Cross-calibration of ALI (A) and ETM+ (E)

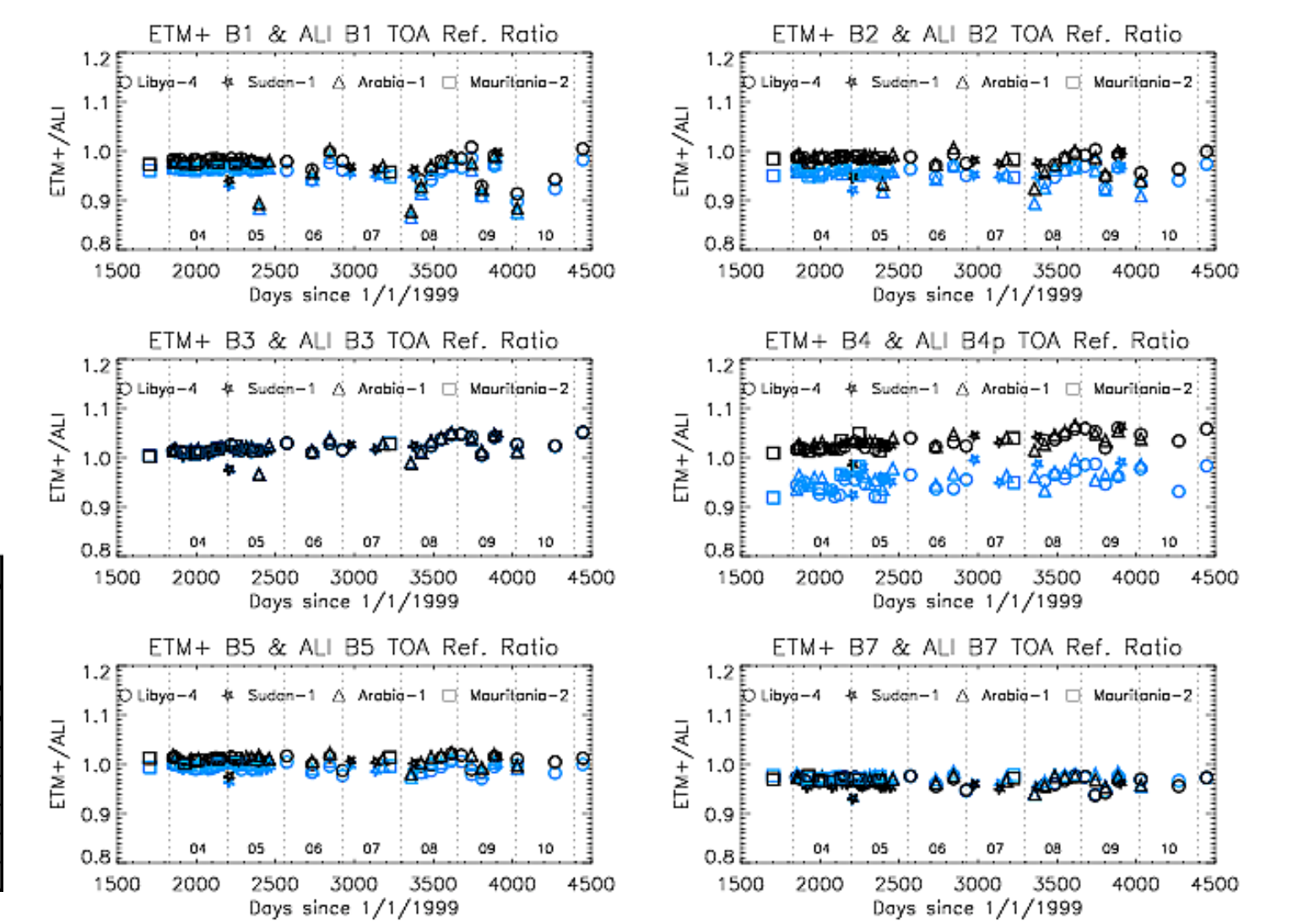| ETM+ Band	ρETM+/ρALI Average	% difference (E-A)/A%	ρETM+/ρALI STD	ρETM+/ρALI Average	% difference (E'-A)/A%	ρETM+/ρALI STD	% difference (BS-AS)/AS%
		Before SBAF			After SBAF		
1	0.955	-4.50%	0.024	0.971	-2.90%	0.025	-1.65%
2	0.953	-4.70%	0.015	0.981	-1.90%	0.016	-2.85%
3	1.019	1.90%	0.015	1.020	2.00%	0.015	-0.10%
4	0.956	-4.40%	0.019	1.022	3.20%	0.019	-7.36%
5	0.994	-0.60%	0.009	1.008	0.80%	0.009	-1.39%
7	0.968	-3.20%	0.011	0.964	-3.60%	0.010	0.41%

Fig. 5. Measured TOA reflectance ratio (MODIS/ALI) over the four PICS. The plot also shows a comparison of before and after SBAF compensation

Table 4. Comparison of the ALI and MODIS measured TOA reflectances before and after spectral compensation.

Cross-calibration of ALI (A) and MODIS (M)

ETM+ Band	ρMODIS/ρALI Average	% difference (M-A)/A%	ρMODIS/ρALI STD	ρMODIS'/ρALI Average	% difference (M'-A)/A%	ρMODIS'/ρALI STD	% difference (BS-AS)/AS%
		Before SBAF (BS)			After SBAF (AS)		
1	0.919	-8.10%	0.030	0.990	-1.00%	0.033	-7.17%
2	0.882	-11.80%	0.031	0.954	-4.60%	0.034	-7.55%
3	0.971	-2.90%	0.023	1.006	0.60%	0.023	-3.48%
4	0.990	-1.00%	0.025	0.986	-1.40%	0.024	0.41%
5	1.111	11.10%	0.026	1.072	7.20%	0.024	3.64%
7	1.162	16.20%	0.025	1.100	1.00%	0.024	15.95%

Summary

- This study summarizes the cross-calibration of ALI, ETM+, and MODIS sensors on the "A.M. constellation" train and explores the impact of spectral compensation on the data.

- All the near-simultaneous images over Libya 4, Mauritania 2, Arabia 1, and Sudan 1 were selected over the mission's lifetime to perform cross-calibration between the three sensors.

- Spectral issues with this cross-calibration approach were investigated and SBAFs were developed for analogous spectral bands where the spectral signature of the target was simulated using EO-1 Hyperion data.

- The cross-calibration results showed the ALI agrees with ETM+ within 4%. Since the RSR of these two sensors are very similar, the spectral compensation did not alter the results much.

- However, due to large differences in the RSR between ALI and MODIS, the spectral compensation resulted in significant improvement in the cross-calibration between ALI and MODIS. The results show that the ALI agrees with MODIS within 5% (except Band 5).

Acknowledgement